COMPARATIVE STUDY OF MAGNETIC Pc1 PULSATIONS BETWEEN LOW LATITUDES AND HIGH LATITUDES: STATISTICAL STUDY

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Abstract: Statistical features of Pc1 pulsations are studied on the basis of data obtained at low- and high-latitude stations, Memambetsu in Japan and Syowa Station in Antarctica, during the period from January 1977 to January 1979. The observed features of high-latitude Pc1 can be divided into three groups, *i.e.*, HM chorus, periodic emission and others (IPDP, Morning IPDP, dot, etc.). For the periodic emission, the generation mechanism is expected to be common to low and high latitudes.

1. Introduction

In company with the developments of the magnetic tape recording system and the dynamic spectral analyzer, Pc1 pulsations (0.2–10 s in period) have been analyzed experimentally by many research workers since IGY (SAITO, 1960; HEACOCK and HESSLER, 1962; KATO and SAITO, 1964; TROITSKAYA, 1967; KAWAMURA, 1970; KOKUBUN, 1970; SAKURAI, 1975; FRASER, 1975; TOYA *et al.*, 1979). The theoretical works for Pc1 have been also developed by CORNWALL (1965), JACOBS and WATANABE (1966) and GENDRIN (1970) for the Pc1 generation mechanism, while by TEPLEY and LANDSHOF (1966), MANCHESTER (1966) and GREIFINGER and GREIFINGER (1968, 1973) for the Pc1 ionospheric duct propagation. In spite of the above-mentioned many research works, several problems have still remained on Pc1.

One of the unsolved problems is a diurnal variation of Pc1 occurrence. Different types of the diurnal variation of Pc1 occurrence have been reported by many research workers (BENIOFF, 1960; SCHLICH, 1963; KATO and SAITO, 1964; HEACOCK and HESSLER, 1965; TROITSKAYA, 1967; KOKUBUN and OGUTI, 1968; KAWAMURA, 1970). They are summarized as follows: Pc1 occurrence maximum time is in the daytime at high latitudes, whereas it is mostly observed in the nighttime at low latitudes. The maximum times seem to shift from the daytime to the nighttime at about

60° in geomagnetic latitude. However, the above-mentioned apparently contradicting observational results could have arisen from differences in characteristics of the recording system and in analyzing periods. As has been already indicated by YANAGIHARA (1960), compatibilities of the recording system should be strictly examined for the comparison of the characteristics on magnetic pulsations. Analyzing period should be also common for the comparative study.

Concurrent ULF observations have been carried out at the low-latitude Japanese station, Memambetsu, and at the high-latitude station, Syowa Station, Antarctica since January 1976. ULF recording systems installed at the two stations are compatible with each other. The purpose of the present paper is to study the statistical characteristics of Pc1 on the basis of the data at the low latitude (Memambetsu) and at the high latitude (Syowa Station) obtained during the two-year period from January 1977 to January 1979.

Other important problem is a relation of Pc1 to the other phenomena. At present, significant relations between Pc1 and the other phenomena (geomagnetic activity indices, for example) have not been reported sufficiently. In the present paper, the relation of Pc1 occurrence to the development of storm time ring current will also be examined.

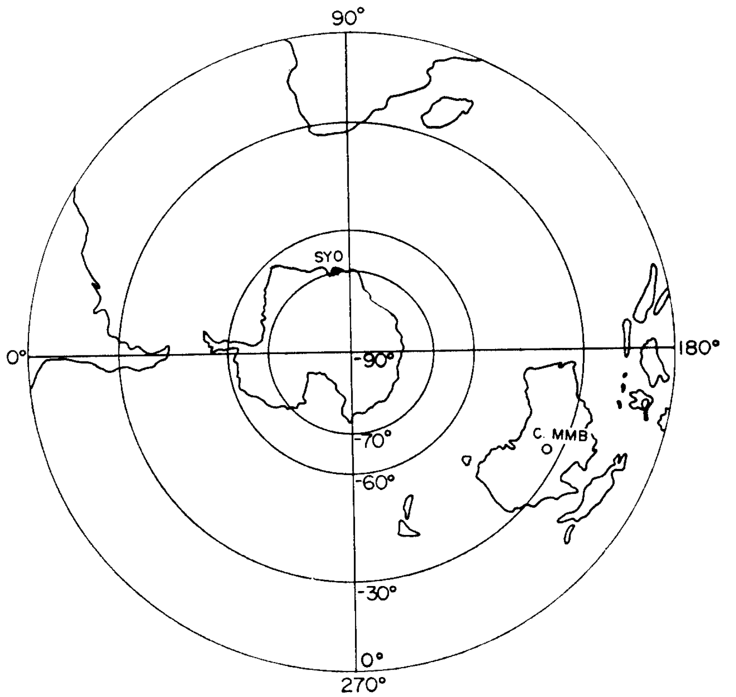

Fig. 1. Geomagnetic locations of Syowa Station in Antarctica and a conjugate point of Memambetsu in Japan.

2. Experimental Method and Data Analysis

In the present paper, data obtained during the two-year period from January 1977 to January 1979 at Memambetsu (MMB) and Syowa Station (SYO) are mainly used for the study on Pc1 magnetic pulsations. The locations of these two stations

Table 1. Geomagnetic locations.

Station	Geographic		Corrected geomagnetic	
	longitude	latitude	longitude	latitude
Memambetsu (MMB)	144°12′E	43°55′N	208.4°	34.0°
Syowa Station (SYO)	39°35′E	69°00′S	72.4°	−66.7°

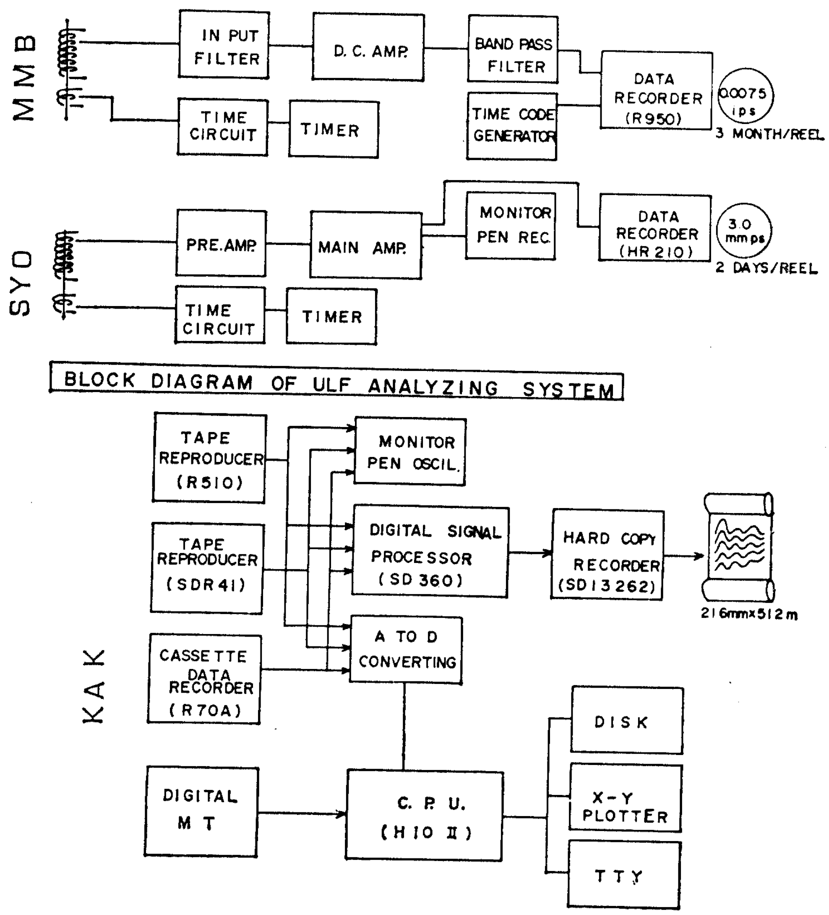

Fig. 2. ULF recording systems installed at Memambetsu and Syowa Station, and ULF analyzing system installed at Kakioka.

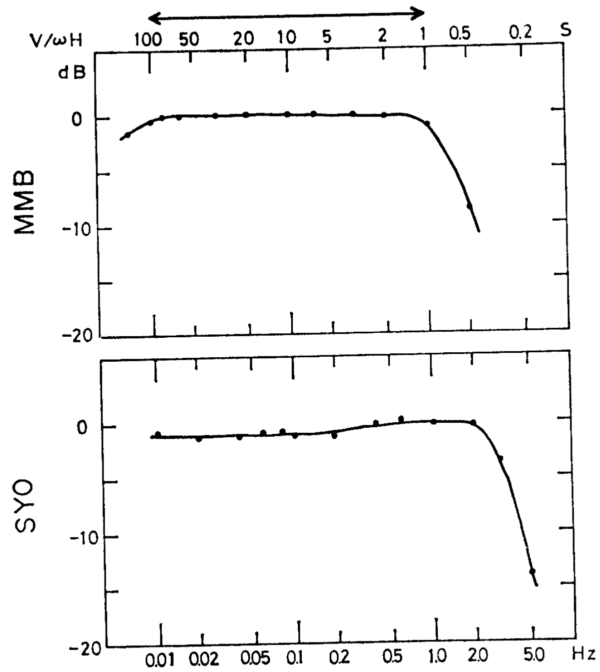

Fig. 3. Frequency characteristics of ULF recording system at Memambetsu and Syowa Station. They are compatible with each other at the two stations in period range from 1 to 100 s.

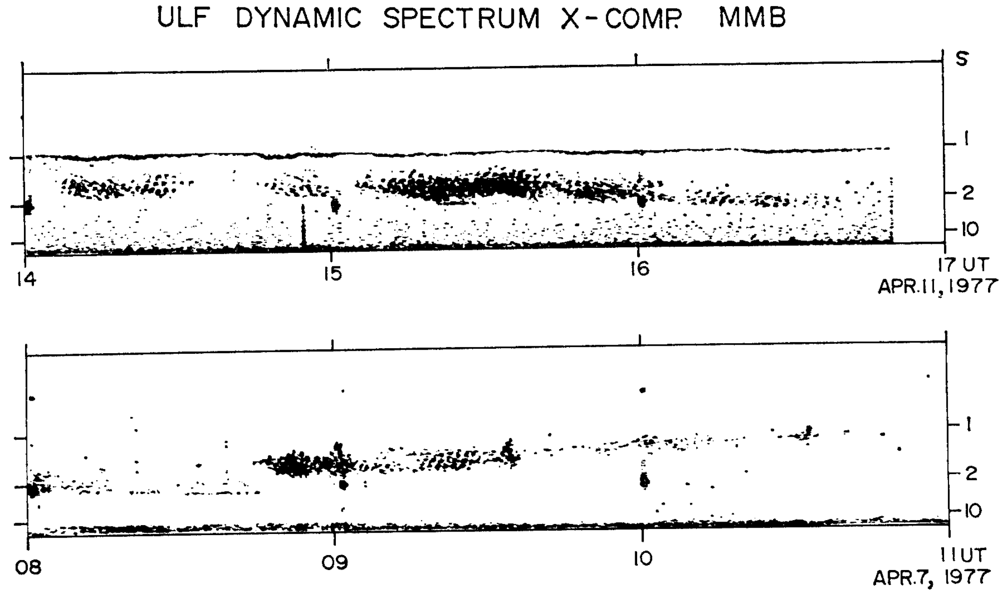

Fig. 4a. Dynamic spectra of Pc1 event observed at Memambetsu.

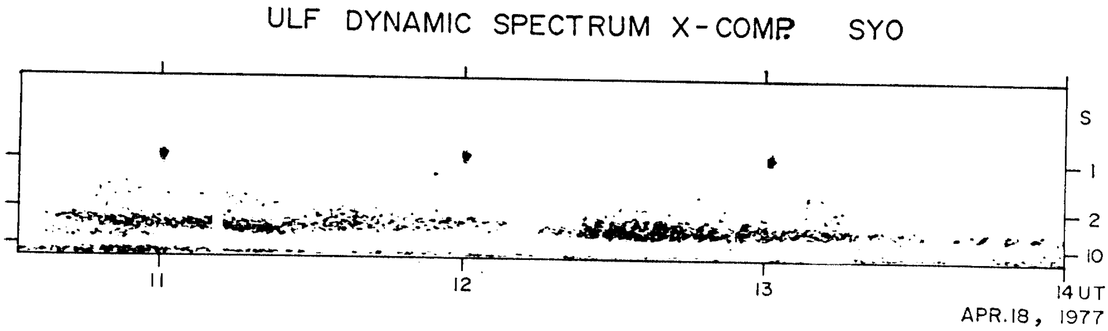

Fig. 4b. Dynamic spectrum of Pc1 event observed at Syowa Station.

are shown in Fig. 1 and Table 1. Occurrence time is an important factor for the study of wave phenomena like Pc1. Japanese standard time (JST) is used for the data obtained at MMB, while magnetic local time (MLT) is used at SYO. Their relations to UT are JST=UT+9 h at MMB and MLT$\sim$UT at SYO, respectively.

As has been already indicated by YANAGIHARA (1960), compatibilities of the recording system should be strictly examined for the comparative study on magnetic pulsations. ULF recording systems installed at MMB and SYO are shown in Fig. 2. As seen in the figure, the systems are similar to each other at the two stations. Magnetic pulsations are observed by means of the induction magnetometer with the three orthogonal core-type sensors at both the stations. Details of the systems should be referred to KAWAMURA and KUWASHIMA (1977) concerning the system at MMB, while to KUWASHIMA (1978) concerning that at SYO. Total frequency (period) characteristics of the systems are illustrated in Fig. 3. As shown in the figure, the observed phenomena are expected to be compatible with each other at the two stations in period range from 1 to 100 s. Pc1 events in the period ranging from 1 to 10 s are mainly treated in the present study.

Data recorded on a magnetic tape are reproduced at an ultra high speed ($\times$4000 for example), and analyzed by a high-speed spectral analyzer (Fig. 2). Examples of dynamic spectra for the typical Pc1 event are shown in Figs. 4a and 4b. Dynamic spectra have been made for 581 Pc1 events at MMB and for 3035 Pc1 events at SYO during the two-year period from January 1977 to January 1979.

3. Classification of the High-Latitude Pc1

In the first place, diurnal variations of any kind of Pc1 occurrence are counted from dynamic spectra by the following method: numbers of 20-min intervals in which any Pc1 event appears are counted. The total counted numbers are 595 at MMB and 2509 at SYO during the period from February 12, 1977 to January 31, 1978. The results are summarized in Fig. 5. At MMB, Pc1 occurrence concentrates in the night hours. This tendency is consistent with the previous results (KAWAMURA, 1970).

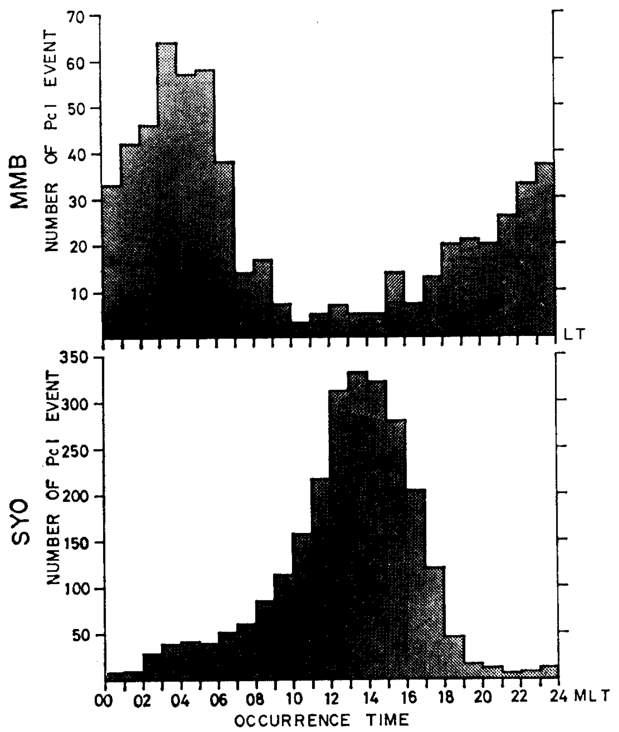

Fig. 5. Diurnal variations in frequency of occurrence of Pc1 event at Memambetsu and at Syowa Station during the period from February 1977 to January 1978.

= Classification =

			(%)
Periodic-Emission	Whistler	22	0.7
	Non-dispersive	327	11.0
	with Diffuse Noise	97	3.2
	Dispersive	80	2.7
	Drifting	32	1.1
Chorus		1543	51.7
Burst		158	5.3
IPDP		66	2.2
Morning-IPDP		22	0.7
Irregular		34	1.1
Unstructured Pc1-2		275	9.2
Dot (single)		168	5.6
Dot (group)		126	4.2
Special event		36	1.2
(Total)		2986	100

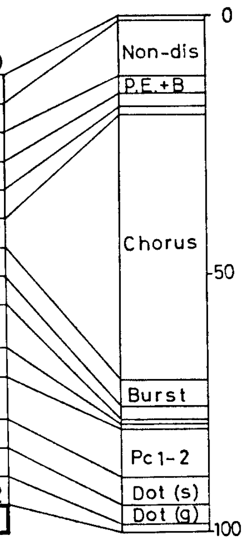

Fig. 6. The result of classification of the high-latitude Pc1.

At SYO, Pc1 occurrence concentrates in the day hours. This tendency also is consistent with the previous results (HEACOCK and HESSLER, 1962; KOKUBUN and OGUTI, 1968). The high-latitude Pc1 shows marked differences from the low-latitude one. However, we treated several kinds of Pc1 as one group in Fig. 5. As shown in the figure, Pc1 occurrence at the high latitude is much larger than that at the low latitude. Many kinds of Pc1 event are considered to belong in Fig. 5. Comparison of features at the low and high latitudes should be performed after a classification of many kinds of Pc1 events observed at the high latitude.

The classification of the high-latitude Pc1 has been tried by TOYA *et al.* (1980). According to their results, the high-latitude Pc1 should be divided into 12 subtypes as shown in Fig. 6. In the present study the high-latitude Pc1 is considered to be divided into three major groups, namely, periodic emission (pearl), hydromagnetic (HM) chorus, and others. HM chorus is most frequently observed at the high latitude (~52%). The occurrence probability of periodic emission is about 18%. The features of HM chorus and periodic emission will be further examined in the next section.

4. Statistical Features of HM Chorus and Periodic Emission at the High Latitude

Fig. 7 shows diurnal variations in occurrence frequency of HM chorus and

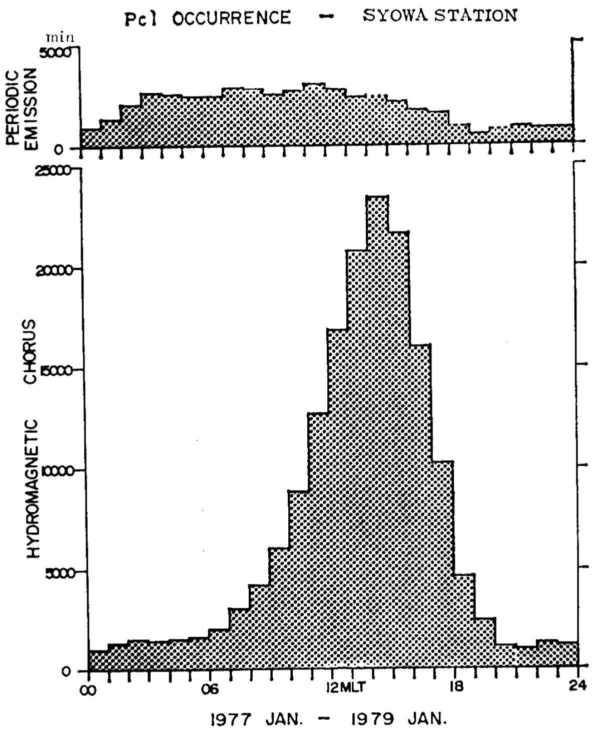

Fig. 7. Diurnal variations in frequency of occurrence of HM chorus and periodic emission at Syowa Station during the period from January 1977 to January 1979.

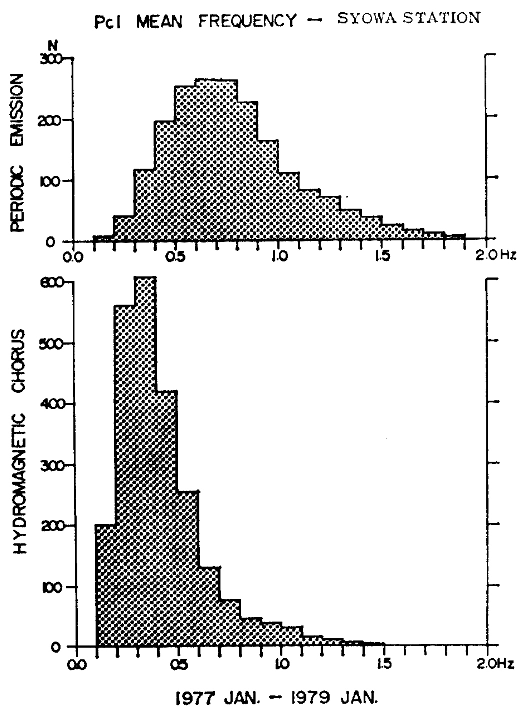

Fig. 8. Histograms of occurrence frequency of HM chorus and periodic emission at Syowa Station as a function of the observed mean frequency.

periodic emission which were observed at SYO during the period from January 1977 to January 1979. The occurrence frequency of HM chorus is conspicuously higher than that of periodic emission. Most of HM chorus are observed in the day hours showing maximum around one or two hours after magnetic local noon (13~14 MLT). Then, they decrease with the progress of time and reach a minimum around magnetic local midnight. They usually show a comparatively low level in the night-time. This characteristic of occurrence is similar to that at the high-latitude Pc1 shown in Fig. 5. On the other hand, the diurnal variation of the periodic emission shows a broad occurrence maximum in the morning hours.

In Fig. 8, the occurrence number of HM chorus and periodic emission is shown as a function of the mean frequency. The difference of the mean frequency is clearly found between the two subtypes. HM chorus shows an occurrence peak around 0.3–0.4 Hz. On the other hand, periodic emission shows an occurrence peak around 0.7–0.8 Hz and this tendency is similar to that of the low-latitude Pc1.

Fig. 9 shows schematic contour diagrams for HM chorus and periodic emission, respectively. HM chorus concentrates in the day hours and its mean frequency is comparatively low. On the other hand, the periodic emission is frequently observed in the early morning hours and its mean frequency is comparatively high. The

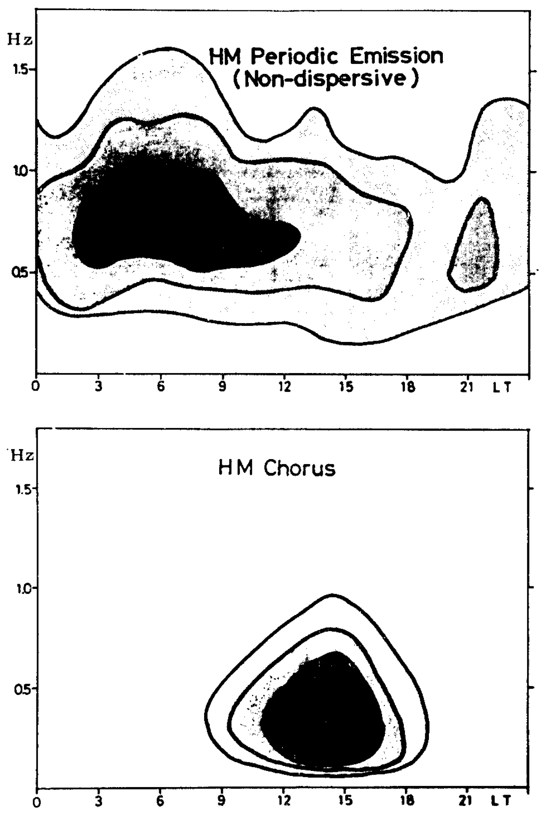

Fig. 9. Schematic contour diagrams for HM chorus and periodic emission at Syowa Station.

features of the periodic emission are similar to those of the low-latitude Pc1. The similarity will be examined in more detail in the next section.

5. Comparison of Features of Periodic Emission between the High and the Low Latitudes

In the preceding section it becomes clear that the statistical features of the periodic emission at SYO are similar to those of the low-latitude Pc1. According to the previous results by KAWAMURA (1970), most of the low-latitude Pc1 are expected to belong to the type of periodic emission. Fig. 10 shows diurnal variations in occurrence frequency of periodic emission which were observed at SYO and MMB during the two-year period from January 1977 to January 1979. Fig. 11 shows the occurrence number of periodic emissions at SYO and at MMB, respectively, as a function of the mean frequency. The periodic emission at SYO shows an occurrence peak around 0.7–0.8 Hz, while that at MMB shows an occurrence peak around 0.8–0.9 Hz. The mean frequency is nearly equal between the low and the high latitudes. The

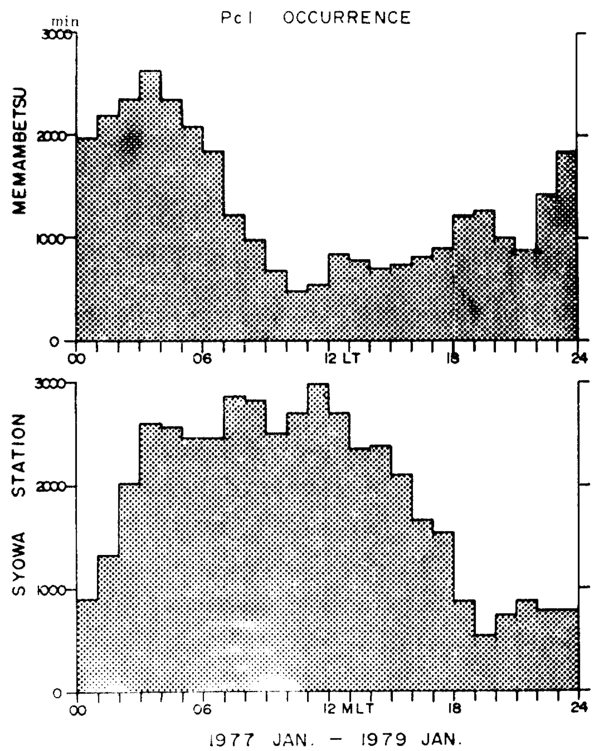

Fig. 10. Diurnal variations in frequency of occurrence of periodic emission at Memambetsu and at Syowa Station during the period from January 1977 to January 1979.

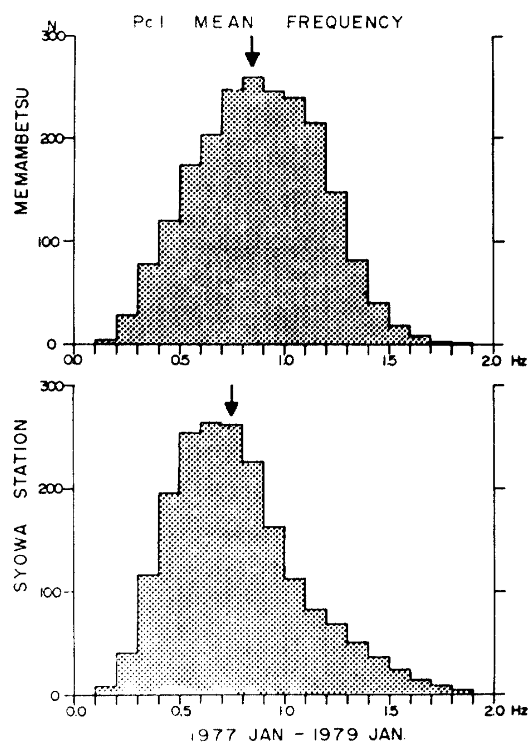

Fig. 11. Histograms of occurrence frequency of periodic emission as a function of mean frequency at Memambetsu and at Syowa Station during the period from January 1977 to January 1979.

absolute numbers of event occurrence are also nearly equal between the low and the high latitudes as shown in Figs. 10 and 11. These observational facts suggest that the source of the periodic emission at the high latitude is common to that at the low latitude.

According to the results by KAWAMURA (1970), the low-latitude Pc1 occurs generally for a few successive days in a calm period following a rather large magnetic storm. In this section, the relation of the occurrences of periodic emission at SYO and MMB to the development of the storm-time ring current (*Dst*) is studied quantitatively.

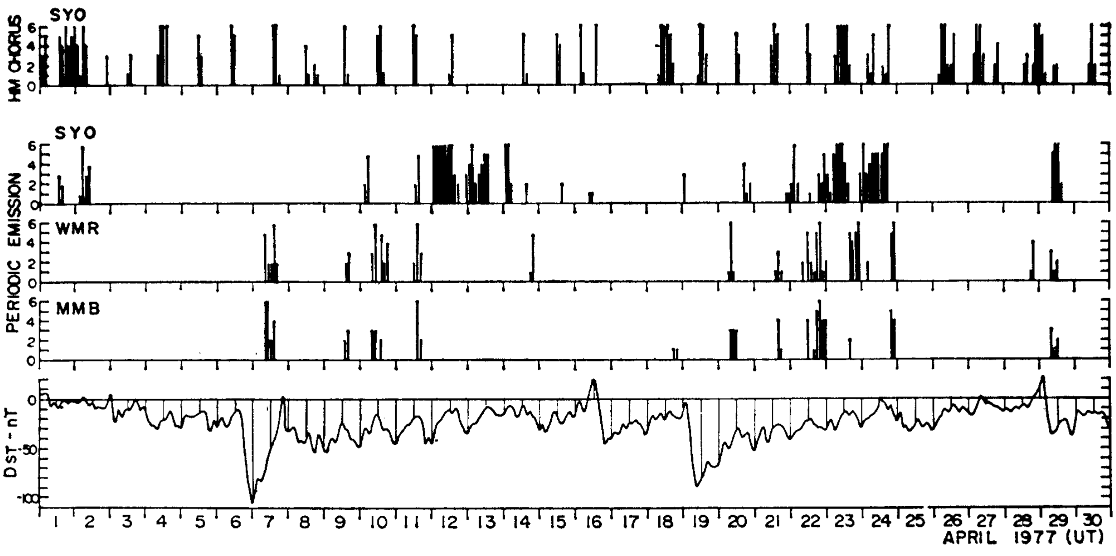

Fig. 12. Pc1 index for HM chorus at Syowa Station (upper), Pc1 indices for periodic emission at Syowa Station, Woomera and Memambetsu (middle), and Dst index (bottom) during the period April 1–30, 1977.

Pc1 index was defined in order to study the relationship of Pc1 activity to the storm-time ring current by the following procedure: each subtype of Pc1 is counted at every 20-min period and the counted numbers are summed at every two-hour period so that the index takes values from 0 to 6. In Fig. 12, Pc1 indices for the periodic emission at SYO and at MMB, and those for the HM chorus at SYO are plotted in relation to *Dst* index for the period from April 1–30, 1977. In the figure, we can find the clear relation that the periodic emission at both SYO and MMB is frequently observed for a few successive days in the recovery-phase of a geomagnetic storm. However, we cannot find any clear relation between the occurrence of the HM chorus and the *Dst* index. The HM chorus is observed always in the daytime independent of the development of the ring current. The results shown in Fig. 12 indicate that the generation mechanism of periodic emission is closely related to the storm-time ring current proton. This relation is examined in more detail. Fig.

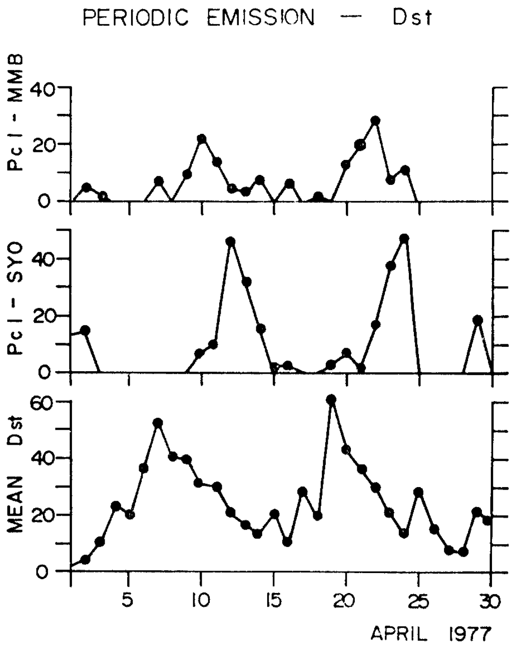

Fig. 13. Daily-sum Pcl indices for the periodic emission at Memambetsu and Syowa Station, and daily-mean Dst index in which the minus sign is changed to plus sign.

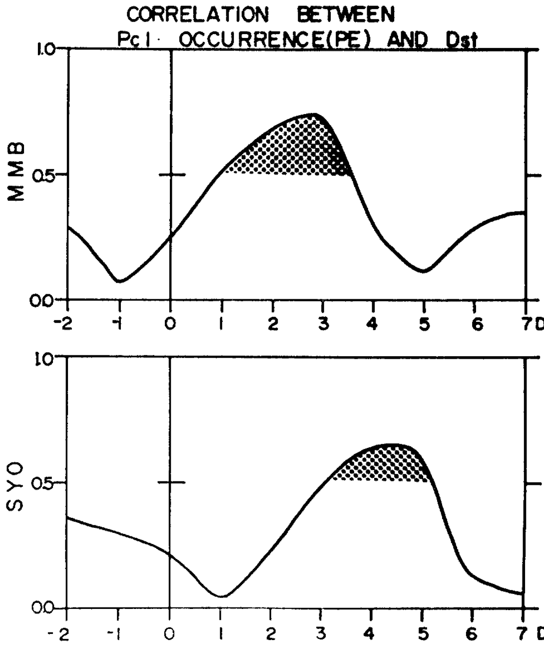

Fig. 14. Cross-correlation functions between the Pcl indices and the Dst index which are shown in Fig. 13. The relations are apparent that at the low latitude the periodic emission is most frequently observed two or three days after the storm main-phase, while it is four or five days after at the high latitude.

13 shows daily-sum Pcl indices for the periodic emission at SYO and MMB, and daily-mean *Dst* index in which the minus sign is changed to plus sign. A tendency that the periodic emission is frequently observed in the recovery-phase of a large magnetic storm is clearly seen in Fig. 13. However, the time lags between the time of storm main-phase and the time of Pcl occurrence peak are not coincident at the high latitude and at the low latitude. In order to examine this tendency quantitatively, the cross-correlation function is calculated with the *Dst* and Pcl indices and the results are illustrated in Fig. 14. At MMB the periodic emission is most frequently observed two or three days after the storm main-phase, while at SYO it is most frequently observed four or five days after the storm main-phase. These observational facts will be discussed in the next section.

6. Discussion

Though Pcl pulsations have been analyzed by many research workers, their global features have not yet been clarified. According to the results by SAITO (1969), the diurnal variation of Pc1 occurrence at the high latitude is greatly different from that at the low latitude. One of the purposes of the present paper is to clarify this unsolved problem. In Sections 3–5, this problem is statistically studied on the basis of data obtained at Syowa Station, Antarctica and at Memambetsu, Japan, during the two-year period from January 1977 to January 1979. ULF recording systems are compatible with each other at the two stations. The analyzed results are summarized as follows.

(1) Diurnal variation: At the low latitude, Pc1 occurrence concentrates in the night hours and shows a maximum at one or two hours before sunrise (~04 LT). On the other hand, at the high latitude, Pc1 occurrence concentrates in the day hours and has a maximum about one hour after magnetic local noon (~13 MLT). The result (1) is consistent with that reported by SAITO (1969).

(2) Seasonal variation: At the low latitude, Pc1 events were most frequently observed in the winter months and were rarely observed in the summer months, while at the high latitude, Pc1 events were most frequently observed in the equinox months.

(3) Mean frequency: There is a distinct difference in Pc1 mean frequency between the high latitude and the low latitude. At MMB, Pc1 event occurrence has a peak around 0.8–0.9 Hz, while at SYO its peak is around 0.3–0.4 Hz.

(4) Pc1 occurrence number: During the two-year period from January 1977 to January 1979, 581 events were observed at MMB, while 3035 events at SYO, respectively.

The Pc1 occurrence number at SYO is more than 5 times larger than that at MMB.

The result (4) indicates that the high-latitude Pc1 consists of various subtypes.

(5) Classification of the high-latitude Pc1: The high-latitude Pc1 is divided into the following three groups:

(a) Periodic emission—Periodic emission corresponds to the phenomena which have usually been called pearls. Occurrence is frequent in the early morning hours and its mean frequency is comparatively high (0.7–0.8 Hz). This group is expected to correspond to the low-latitude Pc1. The occurrence probability is about 18%.

(b) HM chorus—This is most frequently observed at the high latitude. The occurrence probability is more than 50%. Most of HM chorus are observed in the daytime showing a distinct maximum one or two hours after the magnetic local noon (13~14 MLT). The mean frequency is comparatively low (0.3~0.4 Hz).

(c) Others—Several other subtypes are found. They are IPDP, morning IPDP, dot, etc. Although they are very interesting phenomena, detailed discussion would be reserved for other papers.

In the analysis of the high-latitude Pc1, it is expected that the features of HM chorus are more effective than those of any other subtypes like periodic emission. Therefore, the statistical features of HM chorus (Result 5–6) are very similar to those at the total high-latitude Pc1. Because of the large effect of HM chorus which is the characteristic phenomenon only at the high latitude, the statistical features at the high-latitude Pc1 seem to be different from those at the low-latitude one. On the other hand, the statistical features of the periodic emission at the high latitude are very similar to those at the low latitude. This fact means that the generation mechanism is common both at the high and low latitudes.

Next problem is to examine the generation mechanism of the periodic emission. The relation of Pc1 activity to the development of the ring current was studied in order to examine that problem.

(6) Relation of periodic emission to the storm-time ring current: The periodic emission shows a close relation to the development of the ring current. The periodic emission at both SYO and MMB is frequently observed over a few successive days in the recovery-phase of a large geomagnetic storm.

For the mechanism of excitation of Pc1 waves, the following proton-cyclotron instability model was proposed by CORNWALL (1965) and JACOS and WATANABE (1966). In the case where a beam velocity of trapped protons is supersonic with respect to the local Alfvén velocity, hydromagnetic waves are emitted at a frequency corresponding to the occurrence of the cyclotron instability. These hydromagnetic waves bounce along the field lines between the conjugate ionospheres. When a wave packet passes through the proton beam, within each sequence it gains energy from the particles owing to the instability. The results (6) shows that the particle energy of the ring current proton is transferred to the hydromagnetic wave which causes the periodic emission.

(7) Time lag of Pc1 occurrence to the storm main-phase: The time lag of Pc1 occurrence at the low latitude against the time of the storm main-phase is different from that at the high latitude. At MMB, the periodic emission is most frequently observed two or three days after the storm main-phase, while at SYO it is most frequently observed 4~5 days after that.

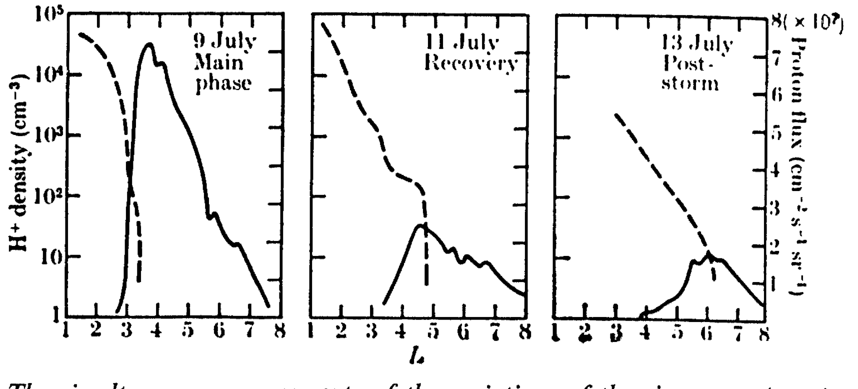

Fig. 15. The simultaneous measurements of the variations of the ring-current proton (31–49 keV) and of the thermal protons in the plasmasphere during the main-phase and the recovery-phase of magnetic storm of 9–13 July 1966 (after TAYLOR et al., 1968; FRANK, 1970; CORNWALL et al., 1970).

The result (7) is a statistical tendency. This result is supported by the following direct observations which are illustrated in Fig. 15. The figure shows the simultaneous measurements of the variations of the ring-current proton (31–49 keV) and of the thermal protons in the plasmasphere during the main-phase and the recovery-phase of magnetic storm of 9–13 July 1966 (after TAYLOR *et al.*, 1968; FRANK, 1970; CORNWALL *et al.*, 1970). During the main-phase (9 July), the ring current was most developed around 4~5 earth radius in the magnetospheric equatorial plane.

However, because of the rapid-inward movement of the plasmasphere, the interaction between the ring-current proton and the thermal proton of the plasmasphere is rare. Two days after (11 July), the plasmasphere was recovered around 4~5 earth radius, where the particle energy would be transferred to the hydromagnetic wave through the cyclotron instability. Two days after, the cyclotron instability region would shift to around 5~6 earth radius with the recovery of the plasmasphere. The above-mentioned relations are schematically summarized in Fig. 16. The wave frequency (f) emitted through the proton-cyclotron instability is as follows,

$$f \simeq \frac{1}{2\pi} \Omega i \cdot \frac{V_A}{v}$$

where Ωi is the cyclotron-frequency, V_A is the Alfvén velocity and v is the beam velocity of the ring current proton. According to the observational results in Fig. 15, the Pc1 frequency may be estimated theoretically. On two days after the main-phase (11 July) when the interaction region is expected to be around 4~5 earth radius, Ωi is ~38 Hz, V_A is ~277 km/s, v is ~1700 km/s and f is expected to be ~0.98 Hz which is similar to the mean frequency of the periodic emission observed at MMB (Fig. 14). Four days after (13 July) when the interaction region is expected to be around 5~6 earth-radius, Ωi is ~14 Hz, V_A is ~534 km/s, v is ~1700 km/s and f is expected to be ~0.69 Hz which is similar to the mean frequency of the periodic emission observed at SYO (Fig. 4). The generation mechanism of the periodic emission is interpreted by the cyclotron instability at the plasmapause as illustrated in Fig. 16.

The close relationship of the periodic emission to the storm-time ring current also is supported by the particle observation by WILLIAMS and LYONS (1974 a, b). According to their result, a pitch angle distribution of the ring-current proton varies from isotropic to anisotropic peaked around $\alpha = \pi/2$ near the plasmapause in the recovery phase of magnetic storm. This fact is interpreted by an occurrence of pitch angle scattering by ion cyclotron waves, which is generated by the interaction of the hot ring current plasma with the cold plasmaspheric plasma.

At both the low and the high latitudes, the periodic emission is observed mostly in the nighttime and rarely in the daytime. Such a distinct diurnal variation shows a close correlation with that of the f_oF2 as is shown in Fig. 17. The emitted Pc1 waves at the plasmapause are converted to the isotropic-mode in the ionosphere and

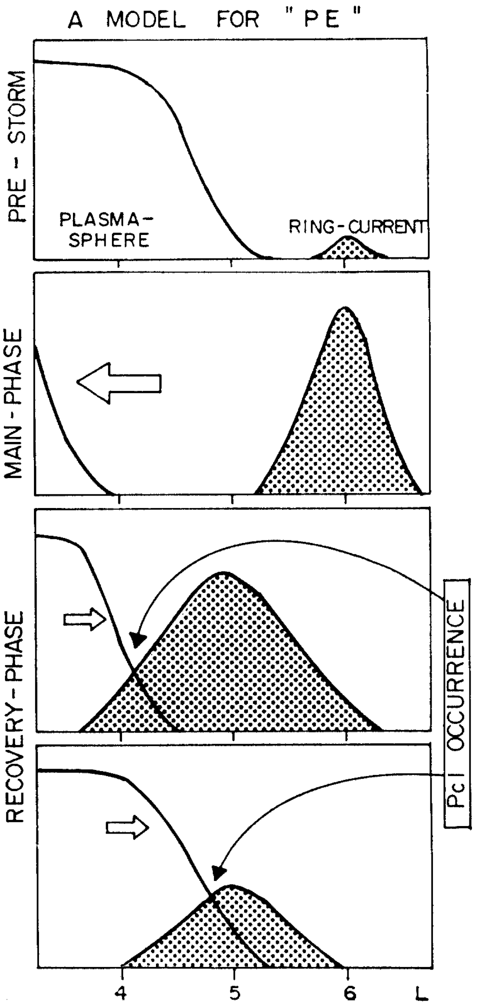

Fig. 16. *A proposed model for the generation of periodic emission.*

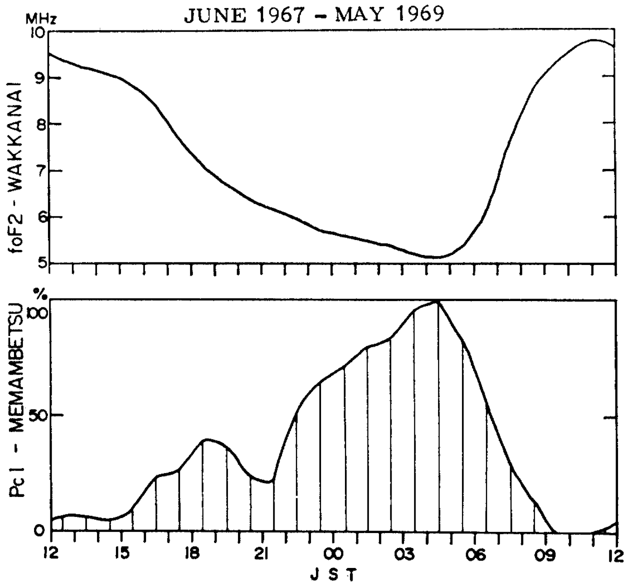

Fig. 17. *Diurnal variation of Pc1 occurrence at Memambetsu and f_0F2 at Wakkanai during the period from June 1967 to May 1969.*

then propagate through a duct near the ionospheric $F2$ layer to both the lower and the higher latitudes (TEPLEY and LANDSHOFF, 1966; MANCHESTER, 1966). In the duct propagation, Pc1 hydromagnetic waves should have suffered some attenuation by absorptions. The attenuation would increase with the increase of the electron density in the ionosphere. Therefore, the periodic emission is frequently observed in the nighttime and in the winter months, when the attenuation effect is less due to the small f_0F2 (the small electron density) as is shown in Fig. 17.

One of the unsolved problems for Pc1 is the generation mechanism of HM chorus at the high latitude, which is constantly observed in the daytime. We cannot find any clear correlation between the occurrence of HM chorus and the geomagnetic activity (*Dst*, *AE*). This problem will be discussed in our current paper.

References

BENIOFF, H. (1960): Observations of geomagnetic fluctuations in the period range 0.3 to 120 seconds. J. Geophys. Res., **65**, 1413–1422.

CORNWALL, J. M. (1965): Cyclotron instabilities and electromagnetic emission in the ultra low frequency and very low frequency ranges. J. Geophys. Res., **70**, 61–69.

CORNWALL, J. M., CORONITI, F. V. and THORNE, R. M. (1970): Turbulent loss of ring current protons. J. Geophys. Res., **75**, 4699–4709.

FRANK, L. A. (1970): Direct detection of asymmetric increases of extraterrestrial ring current proton intensities in the other radiation zone. J. Geophys. Res., **75**, 1263–1268.

FRASER, B. J. (1975): Ionospheric duct propagation and Pc1 pulsation sources. J. Geophys. Res., **80**, 2790–2796.

GENDRIN, R. (1970): Substorm aspects of magnetic pulsations. Space Sci. Rev., **11**, 54–130.

GREIFINGER, C. and GREIFINGER, P. (1968): Theory of hydromagnetic propagation in the ionospheric waveguide. J. Geophys. Res., **73**, 7473–7490.

GREIFINGER, C. and GREIFINGER, P. (1973): Wave guide propagation of micropulsations out of the plane of the geomagnetic meridian. J. Geophys. Res., **78**, 4611–4629.

HEACOCK, R. R. and HESSLER, V. P. (1962): Pearl-type telluric current micropulsations at College. J. Geophys. Res., **67**, 3985–3996.

HEACOCK, R. R. and HESSLER, V. P. (1965): Pearl-type micropulsations associated with magnetic storm sudden commencements. J. Geophys. Res., **70**, 1103–1111.

JACOBS, J. A. and WATANABE, T. (1966): Amplification of hydromagnetic waves in the magnetosphere by a cyclotron instability process with applications to the theory of hydromagnetic whistlers. J. Atmos. Sci., **28**, 235–253.

KATO, Y. and SAITO, T. (1964): Observation of pc1 and pi1 by a visual type induction magnetometer at middle latitude station, Onagawa. Rep. Ionos. Space Res. Jpn, **18**, 188–196.

KAWAMURA, M. (1970): Short-period geomagnetic micropulsations with period of about 1 second in the middle and low latitudes. Geophys. Mag., **35**, 1–54.

KAWAMURA, M. and KUWASHIMA, M. (1977): On the geomagnetic pulsation Pc (Part II): Middle-low-latitude Pc3. Mem. Kakioka Magn. Obs., **17**, 7–18.

KOKUBUN, S. (1970): Fine structure of ULF emission in the frequency range of 0.1–2 Hz. Rep. Ionos. Space Res. Jpn, **24**, 24–44.

KOKUBUN, S. and OGUTI, T. (1968): Hydromagnetic emissions associated with storm sudden commencements. Rep. Ionos. Space Res. Jpn, **22**, 45–59.

KUWASHIMA, M. (1978): Wave characteristics of magnetic Pi2 pulsations in the auroral region—Spectral and polarization studies. Mem. Natl Inst. Polar Res., Ser. A (Aeronomy), **15**, 79 p.

MANCHESTER, R. N. (1966): Propagation of Pc1 micropulsations from high to low latitude. J. Geophys. Res., **71**, 3749–3754.

SAITO, T. (1960): Period analysis of geomagnetic pulsations by a sona-graph method. Sci. Rep. Tohoku Univ., Ser. 5 (Geophys.), **12**, 105–113.

SAITO, T. (1969): Geomagnetic pulsations. Space Sci. Rev., **10**, 319–412.

SAKURAI, T. (1975): Variations of magnetospheric convection electric fields during substorms as inferred from Pc1 hydromagnetic waves. Planet. Space. Sci., **23**, 611–618.

SCHLICH, R. (1963): Micropulsations de periodes comprise entre 0.5 et 6 s observees dans les regions de hautes et moyennes latitudes. Ann. Geophys., **19**, 347–355.

TAYLAR, H. A., BRINTON, H. C., JR. and PHARO, M. W. (1968): Contraction of the plasmasphere during geomagnetically disturbed periods. J. Geophys. Res., **73**, 961–968.

TEPLEY, L. R. and LANDSHOFF, R. K. (1966): Waveguide theory for ionospheric propagation of hydromagnetic emissions. J. Geophys. Res., **71**, 1499–1504.

TEPLEY, L. R., HEACOCK, R. R. and FRASER, B. J. (1965): Hydromagnetic emissions (Pc1) observed simultaneously in the auroral zone and at low latitudes. J. Geophys. Res., **70**, 2720–2725.

TOYA, T., KUWASHIMA, M. and KAWAMURA, M. (1979): Comparative study of magnetic Pc-type pulsations between the low-latitudes and the high-latitudes (I): Statistical features of Pc1 pulsations. Mem. Kakioka Magn. Obs., **18**, 29–47.

TOYA, T., KUWASHIMA, M., KAWAMURA, M., FUKUNISHI, H. and HIRASAWA, T. (1980): Classification of Pc1 and Pi1 waves observed in high latitudes. submitted to J. Geophys. Res.

TROITSKAYA, V. A. (1967): Micropulsations and the state of the magnetosphere. Solar-Terrestrial Physics, ed. by J. W. KING and W. S. NEWMAN. New York, Academic Press, 213–274.

WILLIAMS, D. J. and LYONS, L. R. (1974): The proton ring current and its interaction with the plasmapause: Storm recovery phase. J. Geophys. Res., **79**, 4195–4207.

WILLIAMS, D. J. and LYONS, L. R. (1974): Further aspects of the proton ring current interaction with the plasmapause: Main and recovery phases. J. Geophys. Res., **79**, 4791–4798.

YANAGIHARA, K. (1960): Geomagnetic pulsations in middle latitude, morphology and its interpretation. Mem. Kakioka Magn. Obs., **9**, 15–74.

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